MARCOPOLO-R: NEAR EARTH ASTEROID SAMPLE RETURN MISSION SELECTED FOR ESA ASSESSMENT STUDY PHASE. M.A. Barucci[1], P. Michel[2], A. Cheng[3], H. Böhnhardt[4], J.R. Brucato[5], E. Dotto[6], P. Ehrenfreund[7], I.A. Franchi[8], S.F. Green[8], L.-M. Lara[9], B. Marty[10], and D. Koschny[11], [1]LESIA-Observatoire de Paris, CNRS, Univ. Pierre et Marie Curie, Univ. Paris Diderot, 92195 Meudon Principal Cedex, France (antonella.barucci@obspm.fr), [2]Univ. Nice, CNRS, OCA, F, [3]JHU-APL, Maryland, USA, [4]MPS, Katlenburg-Lindau, D, [5]INAF-Obs. of Arcetri, I, [6]INAF-Obs. of Roma, I, [7]Univ. of Leiden, NL, [8]Open Univ., Milton Keynes, UK, [9]IAA-CSIC, Granada, E, [10]CRPG, Nancy, F, [11]ESTEC, ESA, NL.

Introduction: MarcoPolo-R is a sample return mission to a primitive Near-Earth Asteroid (NEA) selected in February 2011 for the Assessment Study Phase at ESA in the framework of ESA's Cosmic Vision 2 program. MarcoPolo-R is a European-led mission with a proposed NASA contribution.

MarcoPolo-R will rendezvous with a unique kind of target, a primitive binary NEA, scientifically characterize it at multiple scales, and return a unique pristine sample to Earth unaltered by the atmospheric entry process or terrestrial weathering.

Cosmic Vision 2015-2025 lays out four fundamental questions to be addressed by ESA's mission programme [1]. For the second of these, "How does the Solar System work?", it states: "The natural next step in ESA's exploration of small Solar System bodies would be a sample return mission of material from one of the near-Earth asteroids." A sample return from a primitive NEA also addresses the Cosmic Vision question "What are the conditions for life and planetary formation?" The MarcoPolo-R proposal is based on the previous Marco Polo mission study [2], which was selected for the Assessment Phase of ESA's Cosmic Vision 1 program in 2007. Its scientific rationale was highly ranked by ESA committees but it was not selected for the Definition Phase in 2010 because the estimated costs were higher than the allotted amount for an M class mission.

The aim of the new Assessment Study is to reduce the cost of the mission while maintaining its high science level, on the basis of advanced studies and technologies, optimization of the mission, and consolidation of the collaboration with other partners (NASA, AEB…).

Scientific requirements: The main goal of the MarcoPolo-R mission is to return unaltered primitive NEA material for detailed analysis in ground-based laboratories. The limited sampling provided through collection of meteorites does not offer the most primitive material available in near-Earth space. More primitive material, having experienced less alteration on the asteroid, will be more friable and would not survive atmospheric entry in any discernible amount.

MarcoPolo-R will allow us to study some of the most primitive materials available to investigate early solar system formation processes. Direct investigation of both the regolith and fresh interior fragments is impossible by any means other than sample return.

MarcoPolo-R will provide scientific results that are crucial to answer the following key questions:

1. What were the processes occurring in the early solar system and accompanying planet formation?
2. What are the physical properties and evolution of the building blocks of terrestrial planets?
3. Do NEAs of primitive classes contain pre-solar material yet unknown in meteoritic samples?
4. What are the nature and the origin of the organics in primitive asteroids and how can they shed light on the origin of molecules necessary for life?

MarcoPolo-R will allow the analysis of asteroid material in ground-based laboratories to study the formation of the solar system and its planets, the characterization of an NEA as a representative of a primitive solar system body, and will contribute to the field of astrobiology. The sample will provide a legacy for future generations of scientists with the potential for application of new analysis techniques and instrumentation to address as yet unexplored aspects of planetary science. In addition, in-situ observations, and possible surface measurements shall be made to provide local and global geological and physical context for the returned sample.

Target selection: The baseline target of MarcoPolo-R is the primitive binary NEA (175706) 1996 FG3, which offers a very efficient operational and technical mission profile. A binary target also provides enhanced science return: the choice of this target will allow new investigations to be performed more easily compared to a single object, and also enables investigations of the fascinating geology and geophysics of asteroids that are impossible to obtain from a single object. Precise measurements of the mutual orbit and rotation state of both components can be used to probe higher-level harmonics of the gravitational potential, and therefore the internal structure. A unique opportunity is offered to study the dynamical evolution driven by the YORP/ Yarkovsky thermal effects. Possible migration of regolith on the primary from poles to equator allows the increasing maturity of asteroidal regolith with time to be

expressed as a latitude-dependent trend, with the most-weathered material at the equator matching what is seen in the secondary.
Moreover, sample return from a binary would bring us crucial information: i) that may allow discrimination between the proposed formation mechanisms of binary systems, ii) about the internal composition of the progenitor (as part of the surface of the primary may well correspond to some material that was located in the interior of the progenitor).

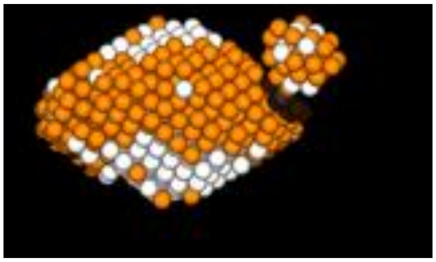

Figure 1: *Image of a simulation of binary formation by YORP spin-up; orange particles were originally located at the surface of the progenitor while white particles were originally below the surface. It can be seen that the pole of the primary is essentially composed of white, initially sub-surface, particles [3].*

Mission Profile: A single primary spacecraft provided by ESA, carrying the Earth Re-entry Capsule (ERC), sample acquisition and transfer system will be launched by a Soyuz-Fregat rocket from Kourou. Several missions have been already studied internally by ESA with two launch windows, in 2021 and 2022, and sample return in 2027 and 2029. They are currently defined as the best options. Earlier or later launches, in 2020 or 2024, also offer good opportunities. Once at the NEA, a number of potential sampling sites (up to 5) are characterized by remote sensing measurements. The spacecraft will then attempt to sample surface material (order of 100g) on the most suitable site (*i.e.* the location yielding the best compromise between science return and risk-mitigation). If the sample collection is not confirmed, up to two additional samplings can be attempted.

The scientific payload includes a camera system for high-resolution imaging, spectrometers covering visible, near-infrared and mid-infrared wavelengths, a neutral-particle analyzer, a radio science experiment and optional laser altimeter. If resources are available, an optional Lander will be added to perform in-situ characterization close to the sampling site, and possibly internal structure investigations.

Several options of the sampling acquisition system are under study at ESA and the best will be selected after two industrial studies are completed**.** The sample and acquisition system proposed originally by the US partners comprises two arms (from JPL), each with a brush wheel sampler (BWS, from JPL), 2 rock chippers (from APL), a sample canister with a sample verification mechanism, and hinge latch and spin eject mechanisms (all from JPL). The BWS has been designed and tested to collect the required sample in less than one second. Alternative collection approaches were studied, including sticky padds, drive tube coring, augers, projectile ejecta collection, cutting wheels, scoops, drag line bucket and gaseous transport devices. The BWS with pyrotechnic rock chippers was considered as the most reliable sample collection approach given uncertainties in surface properties and contact conditions (relative velocity and positioning). It has been tested in air and in vacuum, in Earth gravity and in low gravity on the KC-135A, with many regolith stimulants, including one using the modified lunar regolith size distribution. Other sampling mechanisms can be envisaged and will be investigated along the study.

Conclusion: The large international interest for sample return missions to primitive asteroids is demonstrated by recent selections by main space agencies. NASA selected the mission OSIRIS-REx in the program New Frontiers for launch in 2016 and a return to Earth in 2023, while the mission Hayabusa 2 is now in phase B at JAXA for launch in 2014 and a return to Earth in 2020. Given the diversity of the targeted objects and the different sampling strategies adopted by different missions different kinds and amounts of material will be sampled. It is important that several sample return missions are sent to different objects using different sampling approaches, so that we can enhance our knowledge on the diversity of primitive bodies.

In fact, small bodies, as primitive leftover building blocks of the solar system formation process, offer many clues on the chemical mixture from which the planets formed some 4.6 billion years ago. In addition, they retain material that predates the solar system and contains evidence for interstellar processes.

Current exobiological scenarios for the origin of life on Earth invoke an exogenous delivery of organic matter: primitive bodies could have brought complex organic molecules capable of triggering pre-biotic synthesis of biochemical compounds on the early Earth. Moreover, collisions of NEAs with the Earth pose a finite hazard to life. For all these reasons, the exploration of such objects is particularly interesting and urgent.

References:

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